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International Economics Department
The World Bank
November 1992
WPS 1024

An Exact Approach for Evaluating the Benefits from Technological Change

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How a modified *trade expenditure function* can be used to measure the welfare costs and benefits from technological change — in a model that allows for multiple market distortions and general equilibrium feedback.

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This paper — a product of the International Trade Division, International Economics Department — is part of a larger departmental study of how distortions in commodity markets affect the benefits from, and incentives for undertaking, agricultural research and development projects in developing countries. The study was funded by the Bank's Research Support Budget under research project "Agricultural Policy Reform for Developing Countries" (RPO 676-11). Copies of this paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Dawn Gustafson, room S7-044, extension 33714 (November 1992, 31 pages).

It is commonly believed that taxing agricultural commodities in developing countries, and subsidizing agricultural commodities in industrial countries, reduces incentives in the developing countries for both current production and longer-term investments in capital, knowledge, technology, and infrastructure. It is argued that distortions in agricultural markets have kept investments in research and development, and productivity rates, low in agriculture in developing countries.

Martin and Alston lay the theoretical foundation for empirical studies of how such distortions affect returns to agricultural research and development in developing countries. Earlier studies of the benefits from technological change have typically used partial equilibrium models with Marshallian welfare measures. Such models have not allowed for a general set of market distortions and market interactions.

Techniques recently developed for evaluating welfare in the context of general equilibrium models better measure the implications of trade-distorting policies. Martin and Alston describe how to harness these approaches to evaluate the benefits and costs of technological changes.

They show that a modified *trade expenditure function* can be used to measure welfare changes exactly, with a model consistent with the optimizing behavior of both producers and consumers. They do so in a general setting that allows for multiple market distortions and multiple paths of general equilibrium feedback.

They illustrate this approach using a quadratic form for a profit function that is a component of the trade expenditure function. They spell out, in principle, how to apply this approach with minimal requirements for additional information, using the results from a computable general equilibrium model. They provide a diagram to illustrate the application of the technique.

AN EXACT APPROACH FOR EVALUATING THE BENEFITS FROM TECHNOLOGICAL CHANGE

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AN EXACT APPROACH FOR EVALUATING THE BENEFITS FROM TECHNOLOGICAL CHANGE

Given the central role of technical change in agricultural development, the high and rising pressure on agricultural research budgets, and the need to allocate scarce research resources efficiently, a framework for the analysis of benefits from research and technical change is required. The task is complicated by the wide variety of forms of technical change that affect agriculture. An extensive literature on the evaluation of benefits from research has now developed (e.g., see the survey by Norton and Davis, 1981). This literature has provided many insights into the effects of different types of technical advance on the welfare of particular groups, and in the presence of particular distortions (e.g., Edwards and Freebairn, 1981; Alston, Edwards and Freebairn, 1988). However, it has proved difficult to generalize these insights to situations involving more than one technical change or more than one distortion, especially in cases where more than one price is endogenous so that there is more than one source of general equilibrium feedback (e.g., see Thurman, 1991b, and Alston, 1991, pp. 41-46). In most countries agriculture is characterized by differential distortions among closely-linked markets, so that a methodology that cannot deal with new technology in a distorted multi-market setting is of limited applicability.

In addition, there are some other problems with the state of the art of evaluating technological change. For the most part, the analysis has relied upon standard Marshallian consumer and producer surplus measures which can, at best, provide only approximations to the true welfare effects, are not amenable to generalization, and do not exploit the many advantages offered by a modern, dual formulation. With the simple *ad hoc* supply functions used in most analyses, it has frequently been difficult to distinguish between fixed and variable prices, and to specify exactly which shaded areas were the appropriate measures of welfare change, in the common case of multi-output production possibilities (e.g., see Rose, 1980).

The purpose of this paper is to put forward a general approach to evaluating the effects of technical change that will provide exact measures of the welfare consequences of technical change and will allow the incorporation of multiple distortions and multiple interactions in a general equilibrium setting. At the same time, the approach is able to take advantage of the many insights provided by the previous literature. By using Taylor-series expansions, it is possible to obtain approximate measures which allow an intuitive interpretation of the results obtained using the exact evaluation procedures and which bear a clear relationship to the traditional consumer and producer surplus measures. These measures allow the theoretical basis of the traditional surplus measures to be evaluated and the importance of the approximations on which they are based to be assessed.

The basic formulation of the welfare measures to be utilized is given in the next section of the paper. Following that, three alternative representations of technical change are described and compared, the choice of particular forms of technical change is discussed, and the relationship between the form of technical change and the functional form of the net revenue function, is illustrated. Then, in order to provide an understanding of the effects of important types of technical change, and to illustrate the relationship between the exact approach and the conventional methods in the literature, approximate measures of welfare effects are derived. After that, some empirical issues in implementating the approach are discussed with a view to making clear how the approach may be used in practice. A final section concludes the paper.

The Welfare Formulation

The welfare measures proposed in this paper are based on a modification of the *distorted trade expenditure function* or *balance of trade function* widely utilized in the trade literature (e.g., Vousden, 1990; Lloyd and Schweinberger, 1988; Anderson and Neary, 1992) to evaluate the effects of trade and exogenous shocks. The basic form of the modified trade expenditure function used in this paper is defined for a single-household economy as:[1]

$$(1) \qquad H^t = e(p, w, u^t) - g(p, w, v, \tau) - (p - p^w)'m(p, w, v) - f,$$

and the money-metric measure of total welfare in the economy (H^t) is based on four components: (a) the minimum expenditure necessary to obtain a given level of utility from consumption; (b) benefits in the form of income to owners of factors of production; (c) benefits in the form of government taxation revenues from trade taxes; and (d) net transfers from abroad. These four components are obtained as follows. The function e is the net expenditure function of a representative household for a given vector of domestic prices, p, and a level of utility which is exogenously specified at level u^t since this measure is based upon the Hicksian money-metric measures of welfare change. The function g defines the (maximized) net revenue generated from production in the economy for given domestic prices of outputs, prices of endogenously supplied

[1]Although the discussion in this paper is predominantly couched in terms of dual functions, there is no need for the functional specification used in any particular empirical analysis to be specified directly in terms of these functions. The technology may, instead, be specified using primal production or transformation functions such as the Cobb-Douglas or CES. When the necessary and sufficient conditions for optimization are satisfied, the resulting supply and demand functions are consistent with an appropriate revenue function satisfying all of the theoretical requirements. Similarly, the consumption structure may be specified using a primal specification such as the Klein-Rubin utility function which underlies the popular Linear Expenditure System.

factors, w, a vector of fixed factors, v, and a vector of technology variables, τ, representing the state of the available technology. For a vector of world prices, p^w, the second-last term in equation (1) is the government revenue generated by tariffs (or spent on export subsidies). It is calculated as the inner product of the vector of trade taxes on each commodity $(p-p^w)$ and the vector of import levels, m, which are determined by product and factor prices and the resource endowment. In this standard formulation, it is assumed that these tariff revenues are redistributed costlessly to the consuming household. Finally, f, is the financial inflow from abroad, in the form of net transfers, net factor income flows, or foreign borrowings.

The significant modification made here—to the standard trade expenditure function appearing in the trade literature (e.g., Vousden)—is the use, when calculating tariff revenues, of the actual level of imports rather than the quantity of imports that would result if compensation had been made to hold utility at u^f. This approach has a number of advantages over the usual formulation. Firstly, and as argued by Mayshar (1990), it is consistent with the assumption of hypothetical compensation on which all of these measures are based—the use of a compensated import demand function would be appropriate only if compensation were actually paid, rather than being purely hypothetical. Secondly, this approach provides estimates of welfare change that are consistent with the measures obtained by direct evaluation of the expenditure required to achieve the change in welfare occurring in a fully specified general equilibrium model. If preferred, the actual import demands—$m(p, w, v)$—in equation (1) can be replaced with the compensated demands so as to provide a welfare measure based on actual, rather than hypothetical, compensation.

The use of the expenditure function approach also means that money measures of the compensation required to maintain a particular level of utility are derived in a consistent manner, avoiding the discrepancies that can arise when compensation is considered one market at a time (see Thurman, 1991a, p. 1513; Hueth and Just, 1991, pp. 15-18).

The modified trade expenditure function presented in equation (1) can be generalized in a number of ways. Firstly, it can be extended from a single household to any number of households simply by identifying the expenditure and revenue functions associated with each household or household group. Similarly, vertical market linkages through intermediate inputs can be incorporated by identifying separate net revenue functions for the input-supplying and input-using sectors. Domestic taxation on production, consumption or factor returns can be incorporated by distinguishing between the prices paid by demanders and received by suppliers and by accounting for the resulting government revenues in the same way that tariff revenues are incorporated. The assumption that factor returns are redistributed costlessly can be relaxed by specifying that a proportion of the government revenues is lost to costs such as administration or rent seeking (Anderson and Neary).

An exact money-metric measure of the welfare change resulting from technical change can be obtained from equation (1) simply by comparing the net expenditures required to achieve a given level of utility, u^i, under the initial technology, τ_0, and under the new technology, τ_1. The *compensating variation* version of the measure is defined with the utility level in the expenditure function held constant at u^0:

$$(2) \qquad H_1^0 - H_0^0 = H(p_1, p_1^w, w_1, v_1, \tau_1, u^0) - H(p_0, p_0^w, w_0, v_0, \tau_0, u^0).$$

The *equivalent variation* version of the welfare measure is exactly the same as that defined in equation (2), except that utility is held at u^1 rather than u^0.

The Specification of Technical Change

An important insight from the traditional literature on the evaluation of the benefits from technical advance in agriculture is the importance of the particular form of technical change for the size and distribution of benefits. In particular, a parallel shift of supply has been shown to benefit producers regardless of the demand elasticity (unless supply is perfectly elastic when there are no benefits or costs to producers) while a proportional supply shift will surely reduce producer welfare when demand is inelastic (e.g., Scobie, 1977). The choice of assumption about the nature of the research-induced supply shift has been dictated to a great extent by *a prior* choice of functional forms for supply and demand functions, combined with a desire for convenience. In particular, multiplicative shifts typically have been used in conjunction with constant elasticity models and parallel shifts typically have been used with linear models. There are other, less dramatic but still potentially important, implications for the size and distribution of research benefits from other combinations of assumptions about functional forms of supply and demand, elasticities of supply and demand, and the nature of the research-induced supply shift (see, for example, Duncan and Tisdell, 1971; Lindner and Jarrett, 1980; Rose; and Norton and Davis). By analogy, the choice of functional form for a profit or revenue function will have implications for which forms of technical change are analytically tractable and the combination of those choices might well have implications for the size and distribution of the benefits.

Given these insights, it is desirable that the form of technical change specified within the more general specification proposed in this paper should at least be able to capture the broad types of technical change identified in the earlier literature. An important advantage of specifying technical change in terms of the revenue function is that this also makes explicit the need to remain consistent with the basic requirements of a revenue (or profit) function. In the earlier literature, the impact of the specified technical changes on the satisfaction of theoretical requirements by the profit function characterizing the production side of the economy—monotonicity, homogeneity of degree one and convexity in prices, symmetry, and adding-up—were simply not considered. An advantage of explicitly using the revenue function approach is that these requirements from theory can assuredly be satisfied.

The forms of technical change considered in this paper are disembodied technical changes involving various forms of biases. There are three ways in which disembodied technical change can be introduced into a profit function: (a) the direct incorporation of technical change variables in the function (Binswanger, 1974; Kohli, 1991), (b) the use of a distinction between actual and effective quantities and prices, and output- or input-augmenting technical change (see Dixon, Parmenter, Sutton and Vincent, 1982) for very extensive applications of this approach); and (c) the use of a varying-parameter specification in which the coefficients of a static model are themselves functions of technical change.[2] In general form these three specifications may be represented as:

$$\text{(a) } \pi = g(p,w,v,\tau \mid \alpha), \quad \text{(b) } \pi = g(p(\tau),w,v \mid \alpha), \quad \text{(c) } \pi = g(p,w,v \mid \alpha(\tau)),$$

[2]Fulginiti and Perrin (1972) provide an example of this type of approach in a primal specification in which the parameters of a Cobb-Douglas production function themselves are functions of technological change variables.

where π is variable economic profit (i.e., the total return to the fixed factors), all of the variables are as previously defined, and α is a vector of parameters of the profit function. The consequences of these three types of technical change are considered below using a second-order Taylor-series expansion to approximate any arbitrary functional form for the revenue function. For simplicity and concreteness, a quadratic profit function is specified.

Direct Incorporation of Technical Change Variables

The first specification of technical change is well known from the empirical literature on the estimation of flexible functional forms (see Binswanger). Under this approach, the technical change variable(s) enter the profit function in the same way as a quasi-fixed factor would, except that being "public" goods they receive a zero factor return at the level of the firm. In this case, the technical change can be thought of as an increase in the supply of nonrival goods which are provided free to individual producers. Using the quadratic profit function to illustrate this approach yields:

$$\pi = \alpha_0 + \alpha' P + \tfrac{1}{2} P' A P \tag{3}$$

where $P = [p'\ w'\ v'\ \tau']'$ is an n × 1 vector of output prices, input prices, fixed factors, and technology variables, α_0 is an intercept parameter, $\alpha' = [\alpha_1, \ldots, \alpha_n]$ is a 1 × n vector of parameters, and A is an n × n matrix of parameters, α_{ij}. Typically, only a small number of indexes of technical change (τ_i) will be required, and a popular specification involves the use of only one such variable, the time index. Given the choice of a quadratic form in equation (3), these variables will enter the profit function quadratically.

By Hotelling's lemma, differentiation of the profit function with respect to the output prices yields the output supply functions. The input demand functions for the variable inputs are obtained by differentiating with respect to their prices, while inverse input demand functions for the fixed factors can be obtained by differentiating with respect to the quantities of the fixed factor inputs. For the quadratic function represented in equation (3), this will result in the technology variables entering the output supply and input demand functions as linear shift variables. A typical output supply or input demand function arising from this specification is:

$$x_i = \alpha_i + \sum_{j=1}^{n} \alpha_{ij} p_j + \sum_{r=1}^{m} \alpha_{ir} w_r + \sum_{k=1}^{q} \alpha_{ik} v_k + \sum_{h=1}^{s} \alpha_{ih} \tau_h \tag{4}$$

Clearly, the specification represented by equation (4) allows only for parallel shifts in the output supply or input demand equations, since the effect of τ_h on x_i does not depend on either the output or the price level.

Output- or Input-Augmenting Technical Change

Another specification which has been used widely in modeling technical change is the distinction between actual and effective quantities and prices utilized by Dixon et al. Under this approach, technical change is thought of as something that increases the *effective* quantity of a good associated with a given physical quantity. An important feature of this specification is that there is a corresponding change in the effective price of the good. An increase in the effective quantity of a good provided by each physical unit will reduce the effective price relative to the price of the physical units.

Technical change of this nature may come about in many ways, such as an improvement in the physical quality of the good, or from improved information or management which allows the good to be utilized more efficiently. Using this approach, the relationship between physical and effective quantities of a particular good (i.e., input or output), x_i, can be represented by $x_i = x_i^{*}.\tau_i^{e}$, where x_i is the physical quantity of the good; x_i^{*} is the effective quantity of the good and τ_i^{e} is the level of output-augmenting or input-augmenting technical change for good i. The corresponding relationship between actual and effective prices is $p_i = p_i^{*}/\tau_i^{e}$, where p_i^{*} is the effective price of the good; p_i is the actual price and τ_i^{e} is the augmentation factor. When x_i is an input, input-saving technical advance is represented by a decline in τ_i^{e}, which reduces the physical quantity of the input required for one effective unit and also lowers the effective price relative to the actual price. When x_i is an output, an increase in τ_i^{e} represents output-augmenting technical change: an increase raises the physical quantity associated with a given effective quantity and raises the effective price for a given actual price.

Under this specification of technical change, producers are represented as optimizing over effective quantities and prices, rather than actual quantities and prices. This causes changes in the quantities of goods chosen, and hence in the revenues generated. Once the quantities have been chosen, however, the revenues may be calculated by simple multiplication using either the actual or the effective quantities and prices since the τ^{e} terms will cancel under multiplication.

The profit function, incorporating technical change, is defined by replacing the variables in equation (3) with the corresponding effective values of those variables, and eliminating the terms involving the direct technical change variables, as can be seen in equation (3').

$$\pi = \alpha_0 + \alpha' P^{*} + \tfrac{1}{2} P^{*\prime} A P^{*}, \tag{3'}$$

where $P^* = [p^{*\prime}\ w^{*\prime}\ v^{*\prime}]'$. Considering, for simplicity, technical change affecting only the variable output quantities x, and the corresponding prices, p, output supply or input demand is:

(5)
$$x_i^* = \alpha_i + \sum_{j=1}^{n} \alpha_{ij} p_j^* + \sum_{r=1}^{m} \alpha_{ir} w_r + \sum_{k=1}^{q} \alpha_{ik} v_k ,$$

where the x_i^* and p_i^* variables are as defined above. Substituting the definitions of p^* and x^* into equation (5) yields a behavioral function in the actual price and quantity variables:

(6)
$$x_i = \tau_i^e \left[\alpha_i + \sum_{j=1}^{n} \alpha_{ij} (p_j \tau_j^e) + \sum_{r=1}^{m} \alpha_{ir} w_r + \sum_{k=1}^{q} \alpha_{ik} v_k \right] .$$

From inspection of equation (6), a technical advance of this form for commodity i gives rise to a divergent supply shift which is more than proportionate--a combination of a parallel shift (from the impact on the intercept) and a pivotal shift (the impact on the slope is quadratic in τ_i^e).

A Varying-Parameter Approach

A third way of incorporating technical change is to allow all of the parameters of the profit function to be expressed as functions of a *scalar* technology index, τ^P. In this approach it is important that the functions that define the parameters are chosen so that the desired parametric restrictions hold over the region of interest. In equation (3), after discarding the *vector* of technology indexes (τ) so that $P = [p'\ w'\ v']'$, the parameters may be defined as a function of the technology index. For example, assuming a linear relationship:

$$\alpha_0 = \alpha_0^0 + \beta_0 \tau^P; \qquad \alpha_i = \alpha_i^0 + \beta_i \tau^P; \qquad \alpha_{ij} = \alpha_{ij}^0 + \beta_{ij} \tau^P.$$

Then the supply (input demand) functions may be expressed as:

$$x_i = \alpha_i^0 + \beta_i \tau^P + \sum_{j=1}^{n} (\alpha_{ij}^0 + \beta_{ij}\tau^P) p_j + \sum_{r=1}^{m} (\alpha_{ir}^0 + \beta_{ir}\tau^P) w_r + \sum_{k=1}^{q} (\alpha_{ik}^0 + \beta_{ik}\tau^P) v_k, \tag{7}$$

where the variables are as defined above. Clearly this specification permits any combination of slope and intercept changes so that the shifts of supply induced by technical change could be parallel, convergent, or divergent, and a divergent shift could be proportional either in the price direction (i.e., a pivotal shift in Lindner and Jarrett's terminology) or in the quantity direction or it could be nonproportional. Thus any such shifts are, in principle, compatible with economic theory under the assumption of a quadratic profit function.

To see this more clearly, differentiating (7) with respect to the technology index yields:

$$\partial x_i / \partial \tau^P = \beta_i + \sum_{j=1}^{n} \beta_{ij} p_j + \sum_{r=1}^{m} \beta_{ir} w_r + \sum_{k=1}^{q} \beta_{ik} v_k. \tag{8}$$

A number of special cases can be seen by setting some of the technology-changing parameters (i.e, β's) in equation (8) equal to zero. For instance, if all of the parameters except β_i are zero, the supply of x_i shifts in parallel, a result that was obtained earlier by incorporating technical change directly into the profit function. Alternatively, if all of the parameters of this equation except β_{ii} are zero, we have a proportional shift of the supply of β_i in the price direction.

It is also useful to consider directly the implications of this type of specification for the effect of technical change on the value of the profit function. Differentiating the profit function with respect to τ^P yields:

(9) $$\partial\pi/\partial\tau^P = \beta_0 + \beta' P + \tfrac{1}{2} P' B P$$

Comparison of Types of Technical Change

The three approaches above provide great flexibility in the specification of technical change while maintaining consistency with the requirements imposed by economic theory. As was demonstrated above, the direct specification of technology variables in the revenue function leads to parallel shifts in the resulting supply curves while the use of the *effective* quantity/price approach leads to (more than proportional) divergent shifts in these functions. A combination of the two approaches could be used to generate any type of shift in a particular output supply or input demand function believed consistent with observed changes in the technology. For example, a convergent shift in an output supply curve could be generated through a combination of a positive directly output-increasing technical change and a negative output-augmentation. Alternatively, incorporating technical change as an adjustment of parameters—rather than as an argument of the profit function or a modification of its arguments—may be used to represent exactly the types of supply shifts that have been posited in the previous literature.

Implications of Functional Form

The quadratic profit function leads to linear equations for output supply and input demand. Using the quadratic form, different ways of introducing technical change may have different implications for the shifts in the functions. However, it is relatively straightforward to represent technical changes in ways that are consistent with both the various *ad hoc* treatments in the literature and the restrictions on the profit function that are implied by the theory.

In the literature on benefits from technical change, typically parallel shifts have been used in conjunction with linear supply functions and multiplicative (proportional) shifts have been used with constant elasticity functions, primarily for convenience. In the approach proposed here, the approximating function for the model is defined at the level in which we are primarily interested (the money-metric of welfare change) rather than at the level of its derivatives with respect to price (i.e., at the level of supply and demand functions). Thus the effort and potential problems involved in integrating back to compute welfare are avoided.

To illustrate this point, consider the translog profit function that has been widely used in recent years. Since the translog is a quadratic form in logarithms of variables, we can interpret equation (3) as a translog by redefining the variables as logarithms, and we can introduce the alternative types of technical change as for the quadratic profit function. That is,

$$\ell n\, \pi = \alpha_0 + \alpha' \,\ell n\, P + \tfrac{1}{2}\, \ell n\, P' A\, \ell n\, P\,, \tag{3"}$$

where $\ell n\, P = [\ell n\, p' \;\; \ell n\, w' \;\; \ell n\, v' \;\; \tau']'$. The application of Hotelling's lemma to the translog profit function yields output supply (input demand) equations in share-dependent form such that $S_i = p_i x_i/\pi = \partial \ell n\pi/\partial \ell n p_i$.

The direct introduction of technical change (e.g., as by Binswanger) is reflected in a set of additional linear terms in the share equations as follows:

$$S_i = \alpha_i + \sum_{j=1}^{n} \alpha_{ij}\, \ell n\, p_j + \sum_{r=1}^{m} \alpha_{ir}\, \ell n\, w_r + \sum_{k=1}^{q} \alpha_{ik}\, \ell n\, v_k + \sum_{h=1}^{s} \alpha_{ih}\, \tau_h . \tag{10}$$

In this equation, $\partial S_i/\partial \tau_h = \alpha_{ih}$ is a constant and the profit share of the i^{th} output (or input) x_i changes by a constant amount in response to a unit change in the technology index, τ_h. The nature of the impact of technical change on the supply function expressed in the levels of the variables (rather than shares and logarithms) is difficult to see in this case.

Kohli (p. 105) showed that an input-augmenting technical change in a translog cost function would lead to a change in the intercepts of the share equations from the cost function. A similar result holds for output-augmenting technical change in the translog profit function. If we define $\ell n x_j^* = \ell n[x_j/exp(\tau_j^e)] = \ell n x_j - \tau_j^e$ and $\ell n p_j^* = \ell n p_j + \tau_j^e$ and substitute for the quantities and prices in the translog profit function, the implied share equations for outputs and inputs are:

(11) $$S_i = \alpha_i + \sum_{j=1}^{n} \alpha_{ij} \ell n p_j + \sum_{r=1}^{m} \alpha_{ir} \ell n w_r + \sum_{k=1}^{q} \alpha_{ik} \ell n v_k + \sum_{j=1}^{n} \alpha_{ij} \tau_j^e .$$

The similarity between this result and that in equation (10) illustrates the point that alternative forms of technical change that have different implications for net revenues may appear similar in the context of the derived share or supply equations; in other words, a number of different specifications of the underlying technical change might be consistent with a particular specification of output supply. In this case two different specifications of the nature of technical change led to additive effects in share equations that can be distinguished only through the fact that in equation (10) the coefficients on technical change (α_{ih}) are free while in equation (11) they are equal to the corresponding price coefficients.

Finally, the more general varying-parameter approach could be applied in the same way as for the quadratic cost function. While it is not done here, in the interest of saving space, it would be straightforward to apply the type of approach used for deriving equation (7) to the case of the translog or some other functional form.

Interpreting the Measures of the Welfare Effects of Technical Change

The measures of the gains from technical change proposed in this paper require some interpretation if their use is to be accepted. Fortunately, a second-order Taylor-series expansion allows them to be interpreted in an intuitive manner that conveniently demonstrates the linkages between these measures and the diagrammatic, partial equilibrium, treatments.

Consider the following function that corresponds to that in equation (3) but with the vector of technological change variables (τ) entering in a general form, excluding net transfers, and using more compact notation so that p represents all prices of outputs and variable factors and quantities of fixed factors and the *specific* tariffs (t) are defined so that $t = p - p^w$:

(12) $$H = e(p, u) - g(p, \tau) - t'm(p) = z(p, u, \tau) - t'm(p).$$

where $z(p, u, \tau) = e(p, u) - g(p, \tau)$ is the expenditure function for imports. Thus z_p is the vector of *compensated* import demands (in which utility levels are constant) whereas m represents the vector of *uncompensated* import demands (in which utility levels are endogenous).

Suppose technology changes from τ_0 to τ_1 so that the change in welfare, defined as the *compensating variation* for the change in technology, may be represented as:

(13) $$H_1 - H_0 = [e(p_1,u_0) - e(p_0,u_0)] - [g(p_1,\tau_1) - g(p_0,\tau_0)] - t'[m(p_1) - m(p_0)],$$

where p_1 is the vector of prices under the new technology, τ_1. Here we can see that the total welfare change is equal to (a) the compensating variation for the change in consumer welfare due to the price change induced by the technological change (the first term in square brackets), minus (b) the increase in producer profit due to the new technology (the second term in square brackets), minus (c) the change in government tariff revenues due to the new technology (the last term in square brackets). Consider the case where changes in technology can be represented by changes in a scalar index, τ (corresponding either to τ^P in equation (8) or to changes in a particular technological variable, τ_i in equation (4)). A second-order approximation to the welfare effects is:

$$H_1 - H_0 = \frac{\partial H}{\partial \tau}\Delta\tau + \frac{1}{2}\frac{\partial^2 H}{\partial \tau^2}(\Delta\tau)^2 \tag{14}$$

The components of this equation are obtained by differentiating equation (13) with respect to τ. Taking the first derivative of H with respect to τ—at the initial point of approximation—yields:

$$\begin{aligned} H_\tau &= [e_p' - g_p' - t'm_p](dp/d\tau) - g_\tau - t'm_\tau \\ &= [z_p' - t'm_p](dp/d\tau) - g_\tau - t'(z_{p\tau} - c_Y g_\tau), \end{aligned} \tag{15}$$

where c_Y is the effect of a change in income on the vector of quantities consumed.

In equation (15), the first term represents the welfare effects associated with responses to price changes, the second represents the effect on profit (holding prices constant), and the third represents the effects on tariff revenue when imports change (holding prices constant).

In the second line of equation (15), the uncompensated import demand response to changes in technology has been decomposed into a shift of the compensated import demand and an income effect using a type of Slutsky equation in which c_Y is the vector of income effects on consumer (and hence import) demands which is used to capture the income effects of changes in technology (through g_τ). These income effects measure the shifts in the uncompensated import demand functions in response to any changes in income induced by the new technology, a general equilibrium effect that typically is not taken into account in partial equilibrium models of benefits from technical change.

Consider a small open economy, with protection provided by tariffs, so that both domestic prices and the world prices are unaffected by technological change in the home country. In such a case, with exogenous prices, changes in technology affect compensated import demand only through the output effect ($z_{p\tau} = g_{p\tau}$) and equation (15) reduces to

$$\begin{aligned} \partial H/\partial \tau \;=\; H_\tau &= - g_\tau - t'm_\tau \\ &= - g_\tau - t'(z_{p\tau} - c_Y g_\tau) \\ &= - g_\tau - t'(g_{p\tau} - c_Y g_\tau) \end{aligned}$$

so that the welfare effect is simply the increase in producer profit plus the change in tariff revenue.[3] The second derivative may be written as

$$\begin{aligned} \partial^2 H/\partial \tau_i^2 \;=\; H_{\tau\tau} &= - g_{\tau\tau} - t'm_{\tau\tau} \\ &= - g_{\tau\tau} - t'(g_{p\tau\tau} - c_Y g_{\tau\tau}). \end{aligned}$$

Substituting these components into (14) yields:

$$\begin{aligned} (16) \qquad H_1 - H_0 &= - [\, g_\tau \Delta\tau + ½\, g_{\tau\tau}(\Delta\tau)^2 + t'm_\tau\Delta\tau + ½\, t'm_{\tau\tau}(\Delta\tau)^2 \,]. \\ &= - [\, g_\tau \Delta\tau + ½\, g_{\tau\tau}(\Delta\tau)^2 + t'(g_{p\tau} - c_Y g_\tau)\Delta\tau + ½\, t'(g_{p\tau\tau} - c_Y g_{\tau\tau})(\Delta\tau)^2 \,]. \end{aligned}$$

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[3]Increases in tariff stricken imports generate a welfare gain while increases in subsidized imports or exports cause welfare losses. This term is zero in the absence of distortions but a first-order, and hence potentially important, term in the presence of distortions. For a sufficiently large tariff, it is conceivable that the welfare consequences of a productivity increase could be negative, as demonstrated graphically by Johnson (1967).

The first two terms of equation (16) are the welfare gains in terms of increased producer profit and the second two terms are the welfare losses due to reduced tariff revenue.

With technical change of the type represented by τ^P in equation (7), and exogenous prices, there are no second-order effects to consider because the second derivatives vanish ($g_{\tau\tau} = 0$ and $g_{p\tau\tau} = 0$, as can be seen from equation (9) and the fact that $g_{p\tau\tau} = \partial^2 x/\partial\tau^2$) and therefore $H_1 - H_0 = -[g_\tau + t'(g_{p\tau} - c_Y g_\tau)]\Delta\tau$. This measure includes the effects of changes in the technology index on all of the equations of the system of output supplies and factor demands derived from the profit function, and the effects of changes in tariff revenues arising from shifts of the uncompensated import demand due to changes in both output and income. Even with more general types of technical change, the omission of such higher-order terms seems unlikely to lead to serious errors in most cases.

If (a) only one output, x_i, were affected by changes in the technology index, (b) the only distortion in the economy is a tariff on imports of that commodity, and (c) there were no income effects in import demand (i.e., $m_\tau = \partial m_i/\partial\tau = -\partial x_i/\partial\tau$), the welfare change would be equal to

(17) $$H_1 - H_0 = -g_\tau\Delta\tau + t_i(\partial x_i/\partial\tau)\Delta\tau .$$

And, if there were no distortions in the market for that good (i.e., $t_i = 0$), the welfare change would be simply $H_1 - H_0 = -g_\tau\Delta\tau$.[4] For instance, with the quadratic profit function (linear supply) and a change in technology that shifts only the supply function for one output (x_i) in parallel as shown in equation (7), g_τ will equal $\beta_i p_i$ (i.e., $\beta_i > 0$ and $\beta_{ij} = 0$ for all i,j). Since the change in output is $\Delta x_i = \beta_i \Delta\tau$, the welfare change is $\Delta H = -p_i\Delta x_i + t_i\Delta x_i = -(p_i - t_i)\Delta x_i$

[4]Once distortions are introduced, the welfare change also involves the second term in (17).

$= -p_w \Delta x_i$, where an increase in welfare is a negative number because it corresponds to the reduction in net expenditures required to achieve a given level of utility. Thus, in this extremely simple case, the appropriate approach involves evaluating the quantity increase at world prices, a widely used rule of thumb for measuring research benefits.

Even for this particular type of technical change, this rule of thumb breaks down when any of the special assumptions that underlie it are relaxed. In particular, when other markets are distorted, and there are induced changes in quantities of other goods, there will be additional effects on government revenues to consider. Such induced changes in quantities might come from linkages in supply or demand.

For instance, even where prices are exogenous, many forms of technical change can be expected to change the supply of more than one commodity. An output-augmenting productivity increase in corn is likely to draw resources away from competing crops such as soybeans, affecting the volume of trade in both corn and soybeans and, assuming there are distortions in both markets, the government revenues from trade taxes or subsidies in both markets. The incorporation of this type of technical change requires a further generalization of equation (17) to include effects on tax revenues across all commodities

(18) $$H_1 - H_0 = - g_\tau \Delta \tau + [\ \Sigma_j\, t_j(\partial x_j/\partial \tau)\ ]\Delta \tau\ .$$

In addition, as can be seen in the equations above, even when new technology has its direct impact only on one commodity supply function, and prices are exogenous, the fall in import demand is not equal to the increase in output for the good whose supply has shifted (i.e., $\partial m_i/\partial \tau \neq -\partial x_i/\partial \tau$), and not equal to zero for other goods (i.e., $\partial m_j/\partial \tau \neq 0$, for j $\neq$ i), unless income effects are zero. In general, income changes will cause shifts in the import demand equations both for the commodity in question and for other commodities, leading to additional impacts on tariff revenues when the goods are subject to tariffs. These general equilibrium effects mean that the more complete measure of the welfare change is equal to

$$(19) \qquad H_1 - H_0 = -g_\tau \Delta\tau + [\ \Sigma_j\ t_j(\partial x_j/\partial\tau)\ ]\Delta\tau + [\ \Sigma_j\ t_j\ c_{Yj}\ g_\tau\ ]\Delta\tau$$

where c_{Yj} is the j^{th} element of the vector c_Y of income effects on demand, measuring the income effect on demand for good j. In this equation the last term represents the additional tariff revenue changes arising from income effects in import demand. Thus, the rule of thumb has been extended to allow for effects on production or consumption of other goods that are subject to distortions. However, equation (19) still maintains an assumption of exogenous prices. Relaxing that assumption would add significant complexity. While extensions such as these—in going from equation (17) to equations (18) and (19) or beyond—involve major complications and ambiguities in the traditional diagrammatic approach, they are very straightforward with the approach proposed in this paper.

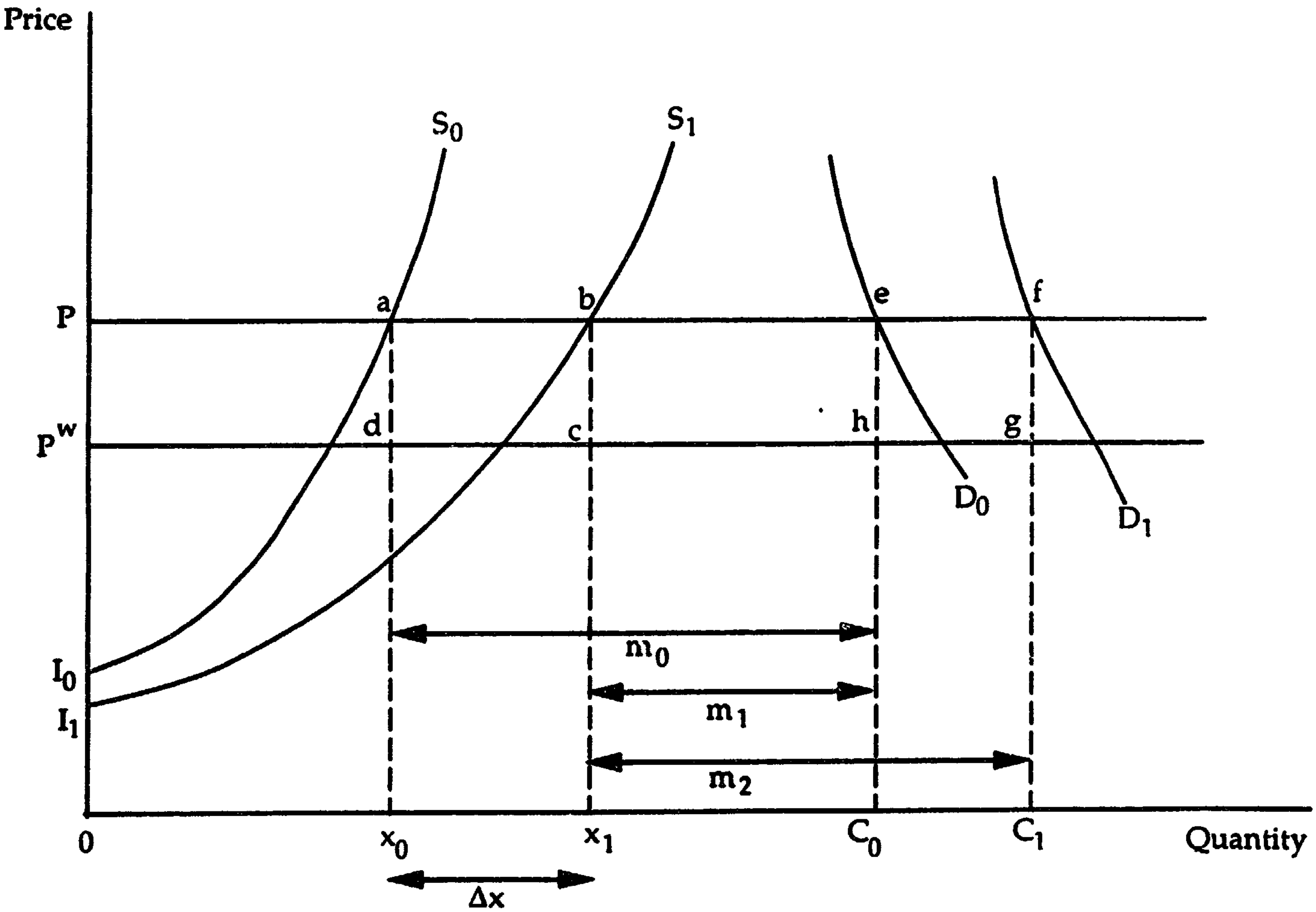
Relationship to Conventional Measures

The general measures of the total welfare impact and its distribution are closely analogous to those that would be obtained in a conventional partial equilibrium analysis of technological change (except that a Hicksian rather than a Marshallian measure of consumer welfare is being used), and are exactly the same as the partial equilibrium measures when the assumptions underlying the partial equilibrium model are valid. That is, the measure from the modified trade expenditure function contains the conventional measures as special cases.

For instance, consider the case shown in figure 1 of a small country with a technological change for an imported good that is subject to a tariff, but with no other distortions in the economy. Under these assumptions both domestic and world prices are exogenous and there are no shifts of supply and demand due to endogenous price changes. A shift in supply from S_0 to S_1 has no effect on consumer prices ($\Delta e = 0$), although it does affect the level of actual spending and, hence, import demand. The benefit to producers, measured as the change in producer surplus, is equal to the shaded area between the two supply curves (I_0abI_1) below the tariff-ridden domestic price, $p_0 = p_1 = p$, and this benefit is equal to Δg from equation (13). The decrease in government tariff revenue is equal to the import tariff multiplied by the change in imports (measured using the uncompensated demand)—area $abcd = (m_1\text{-}m_0)(p\text{-}p^w)$ as measured by the last term in equation (13). However, as noted above, this measure will only be an approximation because endogenous income effects mean that uncompensated demand has shifted from its initial position, D_0. In figure 1, the new uncompensated demand is D_1 reflecting an increase in demand (as would arise if the good were normal and new technology had led to an increase in income). The income effect leads to an increase in imports of this good relative to m_1 (to m_2) and the decrease in tariff revenue in this market is reduced to area $abcd\text{-}efgh = (m_2\text{-}m_0)(p\text{-}p^w)$.

If other markets are subject to tariffs, then there will be additional changes in tariff revenues in these markets to be considered, as is clear from equation (17). These changes in revenues reflect firstly the direct effects of the technical change on the supply of the other commodities and secondly the income effects on demand, and hence import demand, in the other

Figure 1: Welfare Impacts of Technological Change in a Small Country with a Tariff



distorted markets. These effects cannot be incorporated in a single partial equilibrium market diagram, although they can be illustrated in a separate diagram. This can be seen by reinterpreting figure 1 as representing the market for a second good, say y, subject to a tariff equal to p-p^w. Then, shifts from S_0 to S_1 and from D_0 to D_1 can be interpreted as the shifts of supply and demand for good y resulting from technical change in the market for x. For the welfare evaluation, when imports of y increase from m_0 to m_2, the additional effect on tariff revenues is $(m_2$-$m_0)(p$-$p^w)$.

As greater generality is allowed in the partial equilibrium model—in the form of endogenous prices, multiple distortions, and multiple sources of general equilibrium feedback of price changes into shifts of *ceteris paribus* supply and demand functions—it becomes increasingly difficult to identify meaningful measures of welfare change; and evaluating multiple exogenous displacements is even more difficult (e.g., see Thurman, 1991b and Alston for an application to research benefits). However, meaningful, precise, and tractable measures, of both the size of research benefits and their distribution, are available using the approach proposed in this paper.

Empirical Issues in Implementing the Approach

The approach proposed greatly expands the problems for which accurate welfare evaluation can be undertaken—in many cases, without requiring any data or parameters beyond those required for the traditional graphical approach. To clarify the issues involved, we list the steps involved in implementing the approach.

The first requirement is the construction of a behavioral model of consumer demand, producer revenues and government taxation receipts. It is most desirable that this model be consistent with the restrictions imposed by economic theory and correspond exactly with the functional forms for the expenditure and revenue functions used for the welfare evaluation stage. Once a specific functional form has been selected, the requirement of theoretical consistency imposes no informational needs beyond those of the traditional partial equilibrium approach—the own- and cross-price elasticities of demand and supply, and the income elasticities of demand.[5] These parameter values, for the commodities of interest, are sufficient to calibrate complete second-order flexible consumer expenditure and producer revenue functions under the assumption of separability between the commodities of interest and all other commodities.

If the technical change under consideration is sufficiently small that it will not result in an income change large enough to affect the prices of nontraded goods in the economy, then the analysis can proceed in a similar fashion to traditional partial equilibrium analyses. Assuming weak separability, all commodities other than the commodities directly affected by the technical change can be aggregated into a composite good which serves as the numeraire.[6] Only if the technical change is sufficiently large that the resulting income effects will cause changes in the price of nontraded goods will an explicit general equilibrium approach be required. Even then, however, the general equilibrium model can be relatively simple, requiring little more information than the traditional partial equilibrium approach.

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[5]The conventional approach using *Marshallian* consumer surplus does not require income elasticities but these are required in the partial equilibrium approach for *Hicksian* measures of consumer welfare.

[6]An equivalent assumption is implicit under the traditional partial equilibrium approach.

A behavioral model, constructed as described above, may be used to solve for a baseline and a perturbed solution for the price, quantity, expenditure and revenue variables in the model. With the modified trade expenditure function approach, the welfare evaluation is causally posterior to the solution of the model, with the compensated demand functions playing no explicit role in the determination of the equilibrium solution. This is an important operational advantage of the *modified* trade expenditure function approach, since empirical implementation of the *standard* trade expenditure function approach requires that the behavioral model be solved a second time to compute the hypothetical government revenues that would have arisen if consumers were actually compensated from outside the system.

Recall that the trade expenditure function has three components: consumer expenditure, producer revenues, and government tax revenues. Of these, changes in government tax revenues are probably the most straightforward to calculate since these can be read directly from the model solutions. Changes in producer net revenues can be computed by using the value of the revenue function used to generate the supply and demand functions (which will be equivalent to calculating changes in payments to fixed factors in the model). Thus, only consumer expenditure necessarily involves an explicit additional specification: the consumer expenditure function which underlies the consumer demand equations of the behavioral model.

Once a general equilibrium model has been used to compute the prices and quantities under the old and new technologies, the total welfare change and each of its components can be computed. If the supply and demand curves used to generate the prices and quantities are derived directly from the underlying preferences and technology, then the welfare measures will be exact. This would be so, for instance, if the equations representing the demand side of the model were derived explicitly from an integrable consumer expenditure function (e.g., an almost ideal demand system) and the supply side of the economy were derived explicitly from a profit function (such as the translog or the quadratic form shown earlier).[7]

In sharp contrast with the traditional approach, multiple sources of general equilibrium feedback present no problems for the calculation and interpretation of exact measures of the welfare effect and its distribution at any level of aggregation. The procedures identified above can be implemented without modification in the presence of multiple sources of price change and endogenously determined prices. Thus, the seemingly intractable problems identified by Thurman (1991b) are resolved.

Conclusion

In modeling and measuring the total benefit from research and its distribution, agricultural economists have made extensive use of a single-market approach. In doing so they have leant heavily on the results of Just and Hueth (1979) and Just, Hueth and Schmitz (1982) who established conditions under which single-market welfare measures would be meaningful and accurate.[8] However, one of the key conditions for validity of the single-market measures (as emphasized by Harberger (1971) and discussed by Just, Hueth and Schmitz pp. 196-99 and

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[7] This expenditure function involves the unobservable utility index that is not involved in the solution of the model, but which must be held constant (at either its initial or perturbed value) for the welfare evaluation. The trick is to calibrate the expenditure function holding utility constant. For example, if the *almost ideal demand system (AIDS)* functional form were used, the expenditure function could be expressed as follows (Deaton and Muellbauer, 1980, p. 75): $\ln e(u,p) = a(p) + ub(p)$. Transformation of this equation for the value of utility at, say, the initial level of prices, p_0, yields $u_0 = [\ln e(u_0,p_0) - a(p_0)]/b(p_0) = [\ln e_0 - a(p_0)]/b(p_0)$ which may be used to eliminate the unobservable utility index from the calculations. Thus the change in the value of the expenditure function (in logarithms) would be $CV = a(p_1) + [\ln e_0 - a(p_0)]b(p_1)/b(p_0) - \ln e_0$.

[8] Thurman (1991a,b) provides a useful intuitive discussion of the issue and some further results.

Appendix D) is the absence of distortions in other markets. Given the pervasive nature of distortions in agricultural markets, and the strong linkages in production and consumption among individual agricultural commodities, the validity of single-market measures of research benefits is open to question. The absence of tractable alternatives to the single-market approach may have accounted for its continued use in spite of its clear deficiency.

We have shown that it is feasible to relate the welfare gains from technological change to the formal theory of welfare evaluation, rather than relying simply upon graphical techniques. The approach that has been suggested in this paper permits a theoretically sound model to be applied consistently in the estimation of underlying functions, in the simulation of market displacements in response to new technologies, and in the evaluation of the changes in economic welfare, and its distribution, associated with those market displacements.

As well as being an improved way of analyzing and measuring the welfare effects of technical change in cases that have been studied using *ad hoc* methods in partial equilibrium, this approach can be used to evaluate cases where multimarket relationships are important and the partial equilibrium framework has proved inadequate. Particularly important examples in this regard include cases where: (a) there are important interactions among commodities with multiple sources of general equilibrium feedback of price changes from one market to another (e.g., products such as corn and soybeans that are closely related in both production and consumption); (b) it is of interest to disaggregate welfare effects among suppliers of factors of production and where, for that reason, there are complicated interactions among the markets of interest (e.g., in vertically related markets); (c) a particular change in technology affects a number of related markets (e.g., changes in feedgrain supply affecting several livestock-feeding industries, or development of improved inputs applicable in a number of industries); and (d) there is interest in the impacts of multiple market distortions (e.g., impacts of trade liberalization on research benefits).

Other directions in which this work could be extended include: (a) consideration of policy instruments other than border taxes; (b) consideration of changes in product quality associated with new technology (a problem that has proved largely intractable in the *ad hoc* partial equilibrium models but may be tractable in the trade expenditure function approach); and (c) analysis explaining agricultural research investments in a political economy framework, where the size and distribution of benefits matter and where the simplifying assumptions of an undistorted partial equilibrium model are inappropriate.

References

Alston, J. "Research Benefits in a Multimarket Setting." *Review of Marketing and Agricultural Economics* 59(1991): 23-52.

Alston, J.M, G.W. Edwards and J.W. Freebairn. "Market Distortions and Benefits from Research." *American Journal of Agricultural Economics* 70(1988):281-8.

Anderson, J. and P. Neary. "Trade Reform with Quotas, Partial Rent Retention and Tariffs." *Econometrica* 60 (1992): 57-76.

Binswanger, H. "A Cost Function Approach to the Measurement of Elasticities of Factor Demand and Elasticities of Substitution." *American Journal of Agricultural Economics* 56(1974):377-86.

Deaton, A. and J. Muellbauer. *Economics and Consumer Behavior.* London: Cambridge University Press, 1980.

Dixon, P., B. Parmenter, J. Sutton and D. Vincent. *ORANI: A Multisectoral Model of the Australian Economy*. Amsterdam: North-Holland (1982).

Duncan, R. and C. Tisdell. "Research and Technical Progress: The Returns to Producers." *Economic Record* 47(1971):124-9.

Edwards, G.W. and J.W. Freebairn. *Measuring a Country's Gains from Research: Theory and Application to Rural Research in Australia*. Canberra: Australian Government Publishing Service, 1981.

Edwards, G.W. and J.W. Freebairn. "The Gains from Research into Tradeable Commodities." *American Journal of Agricultural Economics* 66(1984):41-9.

Fulginiti, L.E. and R.K. Perrin. "Prices and Productivity in Agriculture." Journal Paper No. J-14462 of the Iowa Agriculture and Home Economics Experiment Station, Ames Iowa, 1992 (forthcoming in the *Review of Economics and Statistics*).

Harberger, A.C. "Three Basic Postulates of Applied Welfare Economics: An Interpretive Essay." *Journal of Economic Literature* 9(1971):785-97.

Hueth, B. and R. Just. "Applied General Equilibrium Welfare Analysis: Discussion." *American Journal of Agricultural Economics* 73(December 1991): 1508-16.

Johnson, H.G. "The Posibility of Income Losses from Increased Efficiency or Factor Accumulation in the Presence of Tariffs." *The Economic Journal* (1967):151-4.

Just, R.E. and D.L. Hueth "Welfare Economics in a Multimarket Framework." *American Economic Review* 69(1979):947-954.

Just, R.E., D.L. Hueth and A. Schmitz. *Applied Welfare Economics and Public Policy*. Englewood Cliffs, New Jersey: Prentice Hall, 1982.

Kohli, U. *Technology, Duality and Foreign Trade: The GNP Function Approach to Modeling Imports and Exports*. Ann Arbor, University of Michigan Press, 1991.

Lindner, R. and F. Jarrett. "Supply Shifts and the Size of Research Benefits." *American Journal of Agricultural Economics* 62(1980):841-44.

Lloyd, P. and A. Schweinberger. "Trade Expenditure Functions and the Gains from Trade." *Journal of International Economics* 24(1988):257-97.

Martin, W. "Measuring Welfare Change in Distorted Open Economies." Contributed Paper to Eastern Economics Association Conference, March 1992, New York City.

Mayshar, J. "On Measures of Excess Burden and their Application." *Journal of Public Economics* 43(1990):263-289.

Norton, G.W. and J.S. Davis. "Evaluating Returns to Agricultural Research: a Review." *American Journal of Agricultural Economics* 63(1981):685-99.

Rose, R. "Supply Shifts and the Size of Research Benefits: Comment." *American Journal of Agricultural Economics* 62(1980):834-44.

Scobie, G.M. "Who Benefits from Agricultural Research?" *Review of Marketing and Agricultural Economics*. 44(1977): 197-201.

Thurman, W. "Applied General Equilibrium Welfare Analysis." *American Journal of Agricultural Economics* 73(1991a):1508-16.

Thurman, W. "On the Welfare Significance and Nonsignificance of General Equilibrium Demand and Supply Curves." Department of Agricultural and Resource Economics, North Carolina State University, 1991b.

Thurman, W.N. and M.K. Wohlgenant. "Consistent Estimation of General Equilibrium Welfare Effects." *American Journal of Agricultural Economics* 71(1989):1041-5.

Vousden, N. *The Economics of Trade Protection*. Cambridge: Cambridge University Press, 1990.

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